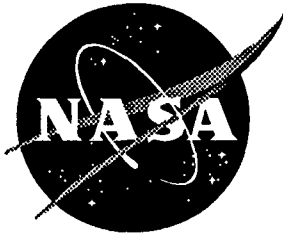


NASA Contractor Report 195048



NASA-CR-195048
19950023831

Development of LaRCTM - IA Thermoplastic Polyimide Coated Aerospace Wiring

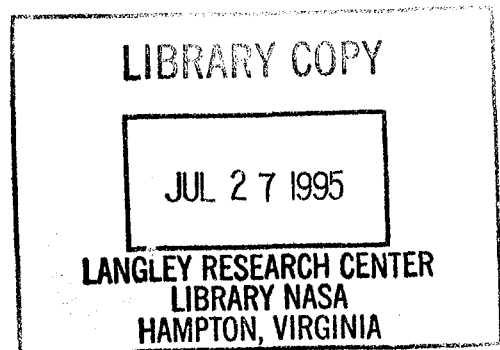
Jack Keating
Imitec, Inc., Schenectady, New York

FOR REFERENCE
NOT TO BE TAKEN FROM THIS ROOM

Contract NAS1-20121

March 1995

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681-0001





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INTRODUCTION

It was the objective of this contract, NAS1-20121, to prepare and extrude an appropriate LaRC™ IA polyimide onto aircraft wire and evaluate the polymers performance in this critical application. NASA Langley invented LaRC™ IA and IAX which show evidences chemical resistance and mechanical properties in advanced composites.

Polyimide tape and coatings have a long successful history in aircraft wire. Successful application of an extrudable polyimide as an aircraft wire coating will result in lower aircraft weight, safer operation, and lower manufacturing costs.

A unique feature of the LaRC™ IA and IAX is their melt processing capability. LaRC™ IA and IAX present products that are extrudable, moisture resistant, light in color, and suitable for extremes of heat and cold.

The LaRC™ IAX was successfully extruded onto aircraft wire at a wire and cable manufacturer. The wire coated with LaRC™ IAX polyimide was tested in accordance with MIL-W-227595E requirements at Barcel Wire & Cable. Excellent properties were obtained.

Overview of Project and Accomplishments

In this contract, LaRC™ IAX polyimide was successfully extruded onto 20 gauge, stranded aircraft conductor - ASTM B 33 (tin coated copper wire), resulting in a commercial quality product meeting the requirements of MIL-W-22759. In this report details and test results are described. This includes extrusion requirements, tooling, extrusion conditions, observations, wire test methods and results.

Imitec in cooperation with Barcel Wire & Cable manufactured aircraft wire from extruded LaRC™ IAX with excellent properties. These properties include, abrasion resistance, dielectric strength, low weight, dimensions, non-burning, non-blocking, solvent resistance, low temperature capability, low shrinkage, 200° and 230° C properties.

It was an objective of this contract to identify a suitable LaRC™ IA/IAX polyimide for extrusion onto aircraft wire and evaluate the polymer's performance in this critical application. Imitec chose the LaRC™ IAX variation based on its toughness and chemical resistance. We identified a molecular weight suitable for extrusion and the process to produce such polymer. A company capable of converting the polymer into pellets was selected and conditions for pelletizing found and implemented. Imitec supervised the extrusion of the LaRC™ IAX pellets onto 20 gauge stranded aircraft wire at Barcel Wire & Cable, a manufacturer of aircraft wire. Imitec researched and dictated the extrusion dies, barrel, screw, temperatures, screw speeds, wire construction and testing. Smooth wire, free of voids and meeting dimension specifications was obtained, resulting in excellent test results according to MIL-W-22579.

The wire tests selected in this contract represent some of the most significant properties desired in military and commercial specifications and control documents. The specifications considered include; MIL-W-81381/7 through/23 (Boeing and McDonnell-Douglas, commercial and military); MIL-W-22759-34 through 43 constructions (Grumman, Northrop, Boeing Aerospace and Boeing Commercial Airplane, both military and commercial); composite constructions of new designs.

The details and accomplishments of our work include;

1. Polymer and molecular weight selection.
2. Polymer preparation and purification.
3. Extrusion into pellets, selection of equipment and conditions required.
4. Extruder, accessories and conditions required to produce commercial quality wire.
5. Testing and evaluation.
6. Commercial quality aircraft wire meeting MIL-W-22759 requirements. 6 spools of tested wire from 6 different trials were made; 500 ft each.

1. Polymer and molecular weight selection.

Work accomplished under NAS1-19966 verified that LaRC™ IA and variations invented at NASA Langley have excellent thermal, hydrolytic and mechanical properties. Aircraft wire is a demanding application and now manufactured using polyimide film wrapped wire or extruded Tefzel™ fluoropolymer. Neither of these constructions are completely satisfactory. The polyimides are sensitive to hydrolysis, cracking and do not laser mark. In addition the wrapped wire presents unique processing difficulties. Fluoropolymers are heavy, soft and cold flow. None of these constructions pass wet arc tracking. Arc tracking as a difficulty is superseded by hydrolysis questions, which the LaRC™ polyimides are resistant to.

From previous tests at McDonnell Douglas we know that LaRC™ IA laser marks at 530 nm with 87% transmission of the light and good contrast. It is tough and shows moisture resistance. Advanced composites made from the LaRC™ polyimides have good chemical resistance and the IAX variation passes solvent tests.

Based on the above, Imitec selected the IAX and commenced to make various molecular weights in order to evaluate melt processing and properties. We produced solid polymers using a process discovered and perfected in NAS1-19966. We made molds to manufacture pellets and using the capillary melt rheometer on loan from Langley, commenced to study the rheology, FIG 1, page 3.

IMITEC, INC.

CAPILLARY MELT RHEOMETER TEST DATA (LaRC-IAX)

<u>OFFSET</u>	<u>TEMP. (°C)</u>	<u>LOAD RANGE (Kg)</u>	<u>SPEED (cm/min.)</u>	<u>% LOAD</u>	<u>PRESS. (psi)</u>
4%	375	400	0.6	23	1,840
4%	375	400	2.0	70	5,600
4%	375	2000	6.0	29	11,600
2%	375	2000	0.06	4	1,600
2%	375	2000	0.2	6	2,400
2%	375	2000	0.6	16	6,400
2%	375	2000	2.0	38	15,200
3%	375	2000	2.0	36	14,400
2+4%*	375	2000	2.0	34	13,600
2+4%*	375	2000	6.0	51	20,400
2%**	375	2000	2.0	43	17,200
2%**	375	2000	6.0	57	22,800
2%**	390	2000	2.0	28	11,200
2%**	390	2000	6.0	45	18,000

*50/50

** Molded Pellets

Notes: .03 x 1" capillary.

Imitec refurbished the instrument and added a spinnerette to evaluate fibers pulled from the bottom of the instrument, measuring elongation, voids, solvent resistance, tensile strength. The purpose was to estimate and select the highest viscosity polymer that would pass demanding wire testing.

- Conclusions:
1. 3 % offset would extrude easily - possibly pass mechanical tests.
 2. 2 % offset would raise the pressure in an extruder to a dangerous pressure, greater than 15,000 psi estimate.
Very good properties, probably pass testing.
 3. 4 % offset would extrude easily - will not pass mechanical, solvent tests.
 4. Blending low molecular weight with high molecular weight was inconclusive, as the rheometer uses a ram and there is no mixing.
 5. Powdered LaRC polyimide produced in Imitec's process will not extrude, it must be pelletized. From a study at California Pellet Mill Co., we determined the IAX powder would not press into suitable pellets, but had to be melt pressed. The dry powder could not be deaired, resulting in foam.
 6. The pellets must be dried at 180 to 200° C., otherwise the extrudate will foam and contain voids.
 7. The polymer must be free of solvent to prevent fuming and inclusions.
 8. Melt viscosity data obtained at Cytec, Anaheim showed that IAX has better melt rheology than PEEK polymer - known to be an excellent melt processable polymer, FIG 2., page 5.

2. Polymer preparation and purification.

Based on the conclusions in #1, Imitec prepared 52 lb. of LaRC IAX at a 3 % offset and 54 lb at 2% offset. To facilitate the extrusion of the higher molecular weight material, we made a low molecular weight additive - 10% offset - to be added to the 2% offset.

The polymers were made according to a process developed in NAS1-19966, thoroughly washed with acetone, centrifuged and dried.

The extruder we intended to use at Barcel Wire and Cable would not accommodate a filter, we therefore filtered the monomers and filtered the molten polymer prior to pelletizing.

LARC-IAx 038-023

FREQ (RAD/SEC) = 10

STRAIN (%) = 50%

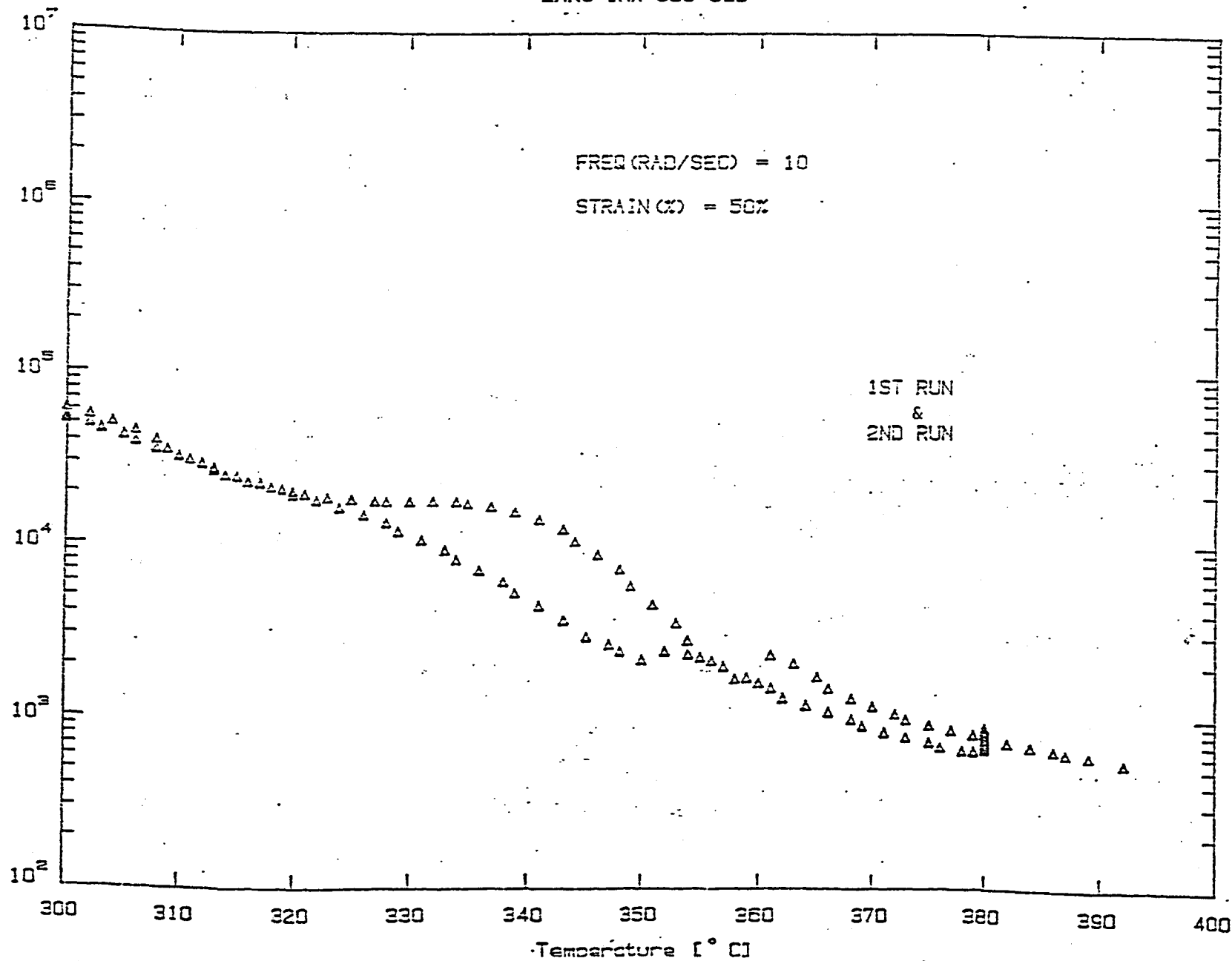
1ST RUN
&
2ND RUN $(\eta) [\text{Pa} \cdot \text{s}]$ 

FIG 2

To develop an understanding of the relationships between the extruder, laboratory melt rheometer and interactions with stranded wire passing through a cross head, we made 15 lb. of 4 % IAX which would extrude easily and generate a reference for later extrusions. The IAX powder was melted and converted into pellets at NASA Langley to expedite the initial trial at Barcel.

3. Pelletizing

Imitec contracted with Killion in New Jersey to extrude the 3 % and 2% (modified with 10 % offset) powder into rods, and chopped into pellets.

The pelletizing at Killion was satisfactory. The rate of pelletizing through their 1.25 inch single screw extruder was slow with a 400, 300, 100 mesh filter pack - 8 lb. per hour. This necessitated two extra days to pelletize the 108 lb.

The 2% offset stressed their 10 horsepower extruder to the limit. The 3 % offset was easily handled, FIG 3, page 7.

As an experiment we added PFA as a flow additive and learned we could blend in a fluoropolymer and make a coextruded product.

Imitec scheduled a trial at Werner & Pfleiderer to evaluate the throughput and processability in a twin screw extruder, versus the single screw at Killion. The LaRCTM polyimides are too tough and shear imparted from a twin screw caused the extruder to overheat. Extensive work on screw design and angles will be required to accommodate a twin screw machine.

Conclusions:

1. 3 % offset pellets extrudes without difficulty, resulting in strong 1/16 inch rods.
2. 2 % offset exceeds the extruder design limits.
3. PFA can be blended and coextruded with the IAX.
4. Quenching the hot extruded polymer in water did not harm it.
5. The IAX is very strong and the laboratory chopping device jammed frequently trying to digest the polymer.
6. A twin screw extruder imparts too much shear and coupled with the toughness of the LaRC polyimides, overheating occurs. Extensive extruder engineering required to accommodate this type of extruder.

Extrusion Conditions for Pelletizing

Extrusion at Killion on single stage extruder, 1.25 inch.
Filter screens of 400, 300, 100 micron in series.

	3 % offset	2 % offset
Zone 1	549 F.	490 F.
Zone 2	600 F.	650 F.
Zone 3	600 F.	685 F.
Zone 4	600 F. Clamp ring	685 F.
Die	570 F.	685 F.
Screw	69 RPM., no pressure	10 RPM, 30% of max psi.
Melt	622 F.	695 F.
	225 RPM, 2000 psi.	30 RPM, 12,000 psi. 75 % of max psi.

FIG. 3

4. Extrusion Conditions Required to Produce Wire.

The exploratory 4 % offset LaRC™ IAX was extruded at Barcel with great success. We used an extruder with a screw and tooling designed for Tefzel™ fluoropolymer. Imitec suggested initial temperatures, screw speeds, die, wire size. A trial designed only to be a first look at the product and analysis of extruder requirements, resulted in a smooth, flexible wire without voids. This trial exceeded all expectations, FIG 4 to 4.4, and we were able to do an extensive engineering study.

Results:

Stranded aircraft wire corresponding to MIL-W-22759/16 and 22759/18 was made using 20 gauge, tin plated copper, meeting ASTM B 33. The coated wire met dimensions and weight requirements. It was flexible and could be knotted.

The conclusions from the first extruder trial:

A. LaRC™ IAX readily extrudes onto stranded wire. It can be stripped from the wire, facilitating connections. It does not shrink back - a serious defect in many polymer insulations.

B. Line speeds up to 485 fpm at 30 rpm screw speed were obtained. The low molecular weight polymer extrudes beyond the capabilities of the extruder. It extrudes much better than PEEK, Tefzel or polyimides supplied by Japanese companies.

C. The screw speed is critical and optimum around 10 rpm. There is a relationship between screw speed and wire properties.

D. Quenching of the hot wire in heated water is important as is the distance from the die tip, 12 - 24 inches. This improves flexibility.

E. If the polymer is not dried or line speeds too slow, the polymer coagulates at the die as the wire is extruded through the cross head.

F. Preheating the wire immediately prior to entering the extrusion tip improves properties.

G. The polymer was easily cleaned from the Hasteloy extruder with copper gauze.

H. Maximum pressure that the extruder will handle was designed to accommodate - 15,000 psi.

First Extrusion Trial at Barcel Wire and Cable Corporation

The test run of the LaRC-IAX resin at Barcel Wire and Cable April 22 was very productive and informative. Many observations were made which warrant further investigation. The experimental conditions and observations are noted below. Samples of most of the trials are included. Where not included, the test speed was too fast to withdraw a sample, but the test location of the product was noted on the spool and a labeled tag was introduced under the winding at that point for future retrieval. Barcel was asked to respool all of the wire into like or singular test condition reels for further sampling and study, and to ship them to Imitec.

The resin was dried for 48 hours at 200°C in a Blue M air recirculating oven.

Constants for this test run:

Extruder setpoint conditions:

Barrel 1	490°F	(254°C)	
Barrel 2	650°F	(343°C)	
Barrel 3	650°F	(343°C)	
Clamp Ring	685°F	(362°C)	bad controller settings, temp varies $\pm 20^\circ\text{F}$
Head 1	685°F	(362°C)	
Head 2	685°F	(362°C)	Temperatures tended to be about 10°F
Head 3	685°F	(362°C)	hotter than set. Instrument reset is off.

Extruder tooling:

 guider tip (pin) diameter: 0.150 inch
 die (hole) diameter: 0.187 inch.

The tooling used was designed for the extrusion of Tefzel as MIL-W-22759/16 wire where the finished diameter is specified to be 0.060 ± 0.002 , or a nominal wall thickness of 0.01125 inch.

Conductor diameter was 0.0375, 20 AWG tin plated copper, manufactured to conductor specification 3C20.

FIG 4.0

Wire as produced is dielectrically tested using a Clinton Instruments 400 Hz sine wave tester. An Audible sound signifies a fault condition.

Test numbers and conditions, notes and observations follow:

Test 1:

Extrusion was started. As the polymer exited the die, die drool immediately started to form. The build-up had to be scraped away at intervals through out the entire test. Extrudate was slightly bubbly on the surface and fairly fluid. There were no signs of degradation, no noticeable darkening in color. Extrudate on wire has some roughness, probably due to die shear and gel particles. Cone length was about 0.5 inches. Occasional gel particles were seen on the wire. When they passed through the cone, they were seen being squeezed to the surface. Line speed was 43 fpm and screw rpm of about 3.3 rpm, and diameter of wire was 0.0616 inch. No wire Preheat was used. No water quench was used. Sample cracks when doubled over.

Test 2:

Wire was extruded as under condition of sample 1 with added preheat applied by the direct flame of three propane torches, since the inductive preheat does not work at slow line speeds. Sample does not crack when doubled.

Test 3:

Wire was extruded as under the condition of sample 1 with added preheat as in sample 2 above. Measurement of the wire temperature by direct contact of the wire to the 1/16 inch diameter probe at the cross head using an Omega Instrument model HH82 digital thermometer indicated that the wire may be 80°C. Water quenching was used. The water was applied about 14 inches from the cone and the temperature was about 85°F.

Test 4:

The same tooling and temperatures were used to make thin wall wire to MIL-W-22759/18, where the finished diameter is specified to be 0.051 ± 0.002 inches. The actual diameter produced when the sample was measured was 0.0505 inch. The line speed was 84 to 85 fpm at 3.3 rpm. All other conditions were the same as in sample 3 above.

FIG 4.1

Note: Occasional dielectric failures have been detected through runs 1 to 4.

Note: As we increased the screw rpm preparing for trial 5, we noted that the fluid flow of the cone improves and tends to heal some of the striation lines that have been present and that appeared to be stretched surface bubbles.

Test 5:

Line speed was 122 fpm with conditions the same as sample 4 but screw rpm not known.

Note: The fluid flow of the cone is now clear, transparent, smooth and defect free. No bubbles, shear or striations are present. Quite excellent extrusion conditions.

Test 6:

Line speed 165 fpm and 6.5 screw rpm.

Test 7:

An attempt was made to determine limiting extrusion conditions. Line speed was increased to where the diameter was 0.0440; frequent cone breaks occurred. When the speed was decreased and the diameter increased to 0.0446, all cone breakage stopped. When cone breaks do occur, it can be seen by the surface regular flow pattern that there is definitely a temperature gradient across the ribbon of polymer exiting from the screw. Therefore, probably little mixing occurs at the shear conditions of this rpm in the barrel. Probably melt turnover could be improved with higher screw speeds. The motor load is now 22%. At 435 fpm and 10 rpm on the screw, the diameter is 0.0448 inch.

Note: All bubbles appear to have been eliminated. Perfectly clear extrudate.

Test 8:

As in 7 above, but 397 fpm and 10.5 rpm, diameter not recorded; see sample

Test 9:

Diameter of MIL-W-22759/18 (0.051 ± 0.002) was extruded at 485 fpm and 30

FIG 4.2

rpm. The plastic has a slight sheen to the surface and the cone length is about 0.625 inch. We may be approaching melt fracture or we may be pumping plastic faster than it can melt before entering the metering section of the screw, i.e. the melt front has moved forward critically. (Usually air entrapment occurs if the solid front moves into the constant compression of the feed section of the screw and high viscosity islands exit from the die annulus. This is not seen.) Screw rpm fluctuations are seen. This could be due to the dead spot in the screw control, or unstable motor conditions, or insufficient heat applied through barrel 2 because of reduced residence time at the faster screw rpm.

The motor load is 85%. We could also be in torque limiting mode due to the extraordinarily high horse power requirement at this rpm. It is important to understand why the horsepower load is so unusually high.

Test 10:

Diameter of MIL-W-22759/16, wire is 0.060, but unstable and varied ± 0.001 or more. Speed is 345 fpm at 30 rpm with a cone of about 1 inch. The extrudate has a light dull finish to cone. The high speed extrusion had cracks on the take-up spool. The conductor preheater cannot keep up with high speed extrusion.

Test 11:

Same as 10 but 187 fpm at 18 rpm, with a quench distance of about 22 inch into room temperature water. The insulation was not as tight and could actually be stripped with a stripping tool.

Note: Clean-up was accomplished by running the barrel until dry. The crosshead was opened and disassembled. As the resin solidified it lost it's adhesion to the Hasteloy surface and was able to be cleaned easily without the use of a purging compound. Small pieces of open copper knitted mesh were introduced into the hopper and used to push remaining material from the screw. The screw was pushed forward a few inches at a time, cleaned with copper gauze and the process repeated until the entire screw was clean. It was cleaned with considerable ease. The barrel was scrubbed with a copper gauze pad on the end of a wooden cleaning rod.

FIG 4.3

From the results of the first trial, Barcel agreed to do the following in preparation for the next extruder trials using the 3 and 2 % offset LaRC™ IAX:

1. Install a laser micrometer for accurate in process measurements.
2. Purchase new extruder screws, using the design suitable for Nylon.
3. Install a new, high temperature extruder barrel.
4. Install a new, high temperature, insulated cross head.
5. Repair the water quench bath.
6. Install a new conductor preheater with fast response time.

Second Extruder Trial at Barcel.

Barcel revamped their extruder based on the previous trial.

This extruder trial resulted in outstanding wire satisfying military specifications, minimum and heavy build. The conductor diameter was 0.0366, 20 AWG tin plated copper. Nine trials were accomplished, FIG 5.1 to 5.5. A tabulated summary of processing conditions is enclosed, FIG 5.6 to 5.5. This includes; die setup, barrel temperatures, head temperatures, pressures, screw speeds, line speeds.

The trial was reviewed with Barcel and a wire test schedule established in view of the excellent appearance of the wire.

During the polymer processing, Imitec discovered and rewired Barcel's main heaters to eliminate a short. We re-configured the programs on the temperature controllers to minimize temperature fluctuations. Drying conditions for the polymer were stabilized and changes made in the drying hopper.

The above changes resulted in the elimination of die dripping, bubbles in the extrusion and resultant fuming.

Introduction of the 2% offset polymer stressed the extruder and temperature changes were made in the screw rpm, line speeds and temperatures. The 3% offset polymer extruded at 40% of maximum motor load. The extrusion temperature of the 2% polymer had to be increased to 375 C.

Later testing showed that trial # 7 resulted in the best wire properties. FIG 7.0, page 23.

Second Extrusion Trial Conditions

Overview:

This report details the experimental conditions and observations during the production of LaRC-IAX insulated wire at Barcel Wire and Cable Corporation in Irvine California on June 8th, 1994. The preliminary evaluation of these wire samples is noted below. A tabulated summary is attached for ease of comparison of processing conditions. Wire samples of the trials are included.

Barcel was asked to respool all of the wire into like or singular test condition reels for further sampling and testing. The testing regime, criteria and specification protocol was discussed and agreed upon in further meetings held at the Barcel facility June 9th with their engineering and quality control personnel.

Preproduction data:

Conductor diameter was 0.0366, 20 AWG tin plated copper.

Wire as produced is electrically tested using a Clinton Instruments 400 Hz sine wave tester. An audible tone signifies a fault condition.

The extrusion resins, both LaRC-IAX 3% offset and 2% offset, were supplied in pelletized form. They were each spread in 3 inch layers and dried at 200°C in open stainless steel pans in a Blue M air recirculating oven for approximately 36 hours. The plant environment was humid (80% RH). We installed an in-line dehumidifying desiccant cartridge bed.

The extruder main drive motor is a 7.5 eddy-current drive through a 10:1 ratio cone drive gear box. The fine wire screw was used, as before, as described in the previous report, dtd. 24 April, 1994.

Tooling for samples 1 through 4 was tip 4-13 and die 4-36 as in the previous run. These were changed to tip 4-01 and die 4-26 for samples 5 through 9.

Sample Data:

1. Extrusion was started. Small point-like bubbles are seen in the emerging melt, which enlarge as they leave the die. There is considerable die drool which builds up quickly after removal or clean-up. Irregular melt flow was experienced indicative of non-uniform temperature gradients or viscosities in the melt. Melt fracture was also seen on the inside of the tip, also indicative of temperature gradients within the cross head and tooling. Surface striations can be observed, probably due to the die drool touching the surface as the molten polymer breaks away from the die. Short term variations in diameter due to localized melt viscosity "islands" causes up to a 20% wall thickness variation.

Extruder set-point conditions:	Barrel 1	490°F	(254°C)
	Barrel 2	639°F	(337°C)
	Barrel 3	639°F	(337°C)
	Clamp Ring	641°F	(338°C)
	Head 1	642°F	(339°C)
	Head 2	638°F	(337°C)
	Head 3	654°F	(345°C)

Product:	Polymer, offset %:	3.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.0592
	barrel pressure, psi:	2700
	screw rpm:	5.9
	line speed, fpm:	86.2

2. Temperatures were reduced with the attempt to eliminate the point-like bubbles. A short to ground was found in the main head heater (head zone 2). The lead wiring was replaced, eliminating the recurrent power supply blown fuse problem. The temperature controllers for the crosshead zones were re-configured to simple proportional controls (the integral and derivative features were turned off) with a proportional zone of 20°F. Temperature fluctuations in the head and die zones were thereby eliminated:

Extruder set-point conditions:	Barrel 1	490°F	(254°C)
	Barrel 2	625°F	(329°C)
	Barrel 3	625°F	(329°C)
	Clamp Ring	625°F	(329°C)
	Head 1	625°F	(329°C)
	Head 2	628°F	(331°C)
	Head 3	628°F	(331°C)

Product:	Polymer, offset %:	3.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.0592
	screw rpm:	7.8
	line speed, fpm:	115.1

FIG 5.2

3. The dehumidifying hopper-dryer moisture indicator light came on. The desiccant bed was changed and the indicator light went off. We found that the hopper access door gasket had degraded with large sections missing along with one of the clamps. A clean rag was stuffed behind the door as a makeshift gasket. The cooling blower on barrel 2 must be run in a manual mode as the wiring interface along with the cooling deviation set-point do not regulate the temperature accurately. Progressively, the bubbles diminished. Die drool slowed and then stopped. Fuming decreased. With many polymers, specially polyolefins, excessive die drool is usually associated with surface adsorbed moisture. The fuming rate appears to also be associated with the moisture content of the polymer.

Extruder set-point conditions:

Same as in 2 above.

Product:	Polymer, offset %:	3.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.0600
	screw rpm:	10.0
	line speed, fpm:	132.7

4. High speed extrusion test.

Extruder set-point conditions:

Same as in 2 above.

Product:	Polymer, offset %:	3.0
	Wire Style equivalent:	Mil-W-22759/18-20 (medium wall)
	Wire diameter, inch:	0.0515
	barrel pressure, psi:	4500
	screw rpm:	9.5
	line speed, fpm:	204.8
	conductor temp, °F:	390

5. Repeat of 4 above but at lower line speed.

Extruder set-point conditions:	Barrel 1	490°F	(254°C)
	Barrel 2	625°F	(329°C)
	Barrel 3	625°F	(329°C)
	Clamp Ring	626°F	(330°C)
	Head 1	623°F	(328°C)
	Head 2	636°F	(335°C)
	Head 3	629°F	(332°C)

FIG 5.3

Product:	Polymer, offset %:	3.0
	Wire Style equivalent:	Mil-W-22759/18-20 (medium wall)
	Wire diameter, inch:	0.051
	screw rpm:	5.2
	line speed, fpm:	116.6
	conductor temp, °F	390

6. Compound was changed to the 2% offset material. When the barrel composition changed, the screw RPM decreased slowly to 0.5 RPM, was very unstable and caused gross cyclical surging. The machine was running in torque limit with no screw speed control. As the screw volume was purged by the 2% polymer, the problem worsened, cumulating with the stalling of the extruder drive. To remedy this situation, the temperatures were set as indicated below. The screw motor was turned off for about eight (8) minutes to permit the temperatures to increase in both the barrel and the screw and to lower the viscosity of the polymer before proceeding because of the danger of breaking the screw or damaging the drive train components.

Extruder set-point conditions:	Barrel 1	600°F	(316°C)
	Barrel 2	675°F	(357°C)
	Barrel 3	675°F	(357°C)
	Clamp Ring	675°F	(357°C)
	Head 1	675°F	(357°C)
	Head 2	675°F	(357°C)
	Head 3	675°F	(357°C)

Product:	Polymer, offset %:	2.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.0605
	barrel pressure, psi:	1000
	screw rpm:	2.5 - 3.0
	conductor temp, °F	no

7. Unstable operation as in (6) above much improved.

Extruder set-point conditions:	Barrel 1	550°F	(288°C)
	Barrel 2	675°F	(357°C)
	Barrel 3	676°F	(358°C)
	Clamp Ring	676°F	(358°C)
	Head 1	666°F	(352°C)
	Head 2	674°F	(357°C)
	Head 3	676°F	(358°C)

FIG 5.4

Product:	Polymer, offset %:	2.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.0588 - 0.0615
	screw rpm:	6.2 - 6.9
	line speed, fpm:	88 - 97.1
	conductor temp, °F	none

8. Some surging still occurs.

Extruder set-point conditions:	Barrel 1	550°F	(288°C)
	Barrel 2	675°F	(357°C)
	Barrel 3	676°F	(358°C)
	Clamp Ring	676°F	(358°C)
	Head 1	666°F	(352°C)
	Head 2	674°F	(357°C)
	Head 3	676°F	(358°C)

Product:	Polymer, offset %:	2.0
	Wire Style equivalent:	Mil-W-22759/16-20
	Wire diameter, inch:	0.059
	barrel pressure, psi:	4300
	screw rpm:	6.2 - 6.9
	line speed, fpm:	88 - 97.1
	conductor temp, °F	390 (est.)

9. 3/8 inch long glossy cone of good consistency with very little fume evolution.

Extruder set-point conditions:	Barrel 1	573°F	(301°C)
	Barrel 2	706°F	(374°C)
	Barrel 3	689°F	(365°C)
	Clamp Ring	686°F	(363°C)
	Head 1	667°F	(353°C)
	Head 2	673°F	(356°C)
	Head 3	675°F	(357°C)

Product:	Polymer, offset %:	2.0
	Wire Style equivalent:	Mil-W-22759/18-20 (medium wall)
	Wire diameter, inch:	0.0525
	barrel pressure, psi:	5000
	screw rpm:	8.5
	line speed, fpm:	176
	conductor temp, °F	390 (est.)

FIG 5.5

LaRC IAX Extrusion Trial 2

Summary of Extrusion Sample Run						
sample	insulation wall style	polymer offset, %	conductor preheat	screw, rpm	line, fpm	pressure, psi
1	heavy	3	none	5.9	86.2	2700
2	heavy	3	none	7.8	115.1	
3	heavy	3	none	10.0	132.7	
4	medium	3	yes	9.5	204.8	4500
5	medium	3	yes	5.2	116.6	
6	heavy	2	no	unstable operation		1000
7	heavy	2	no	6.2	97.1	
8	heavy	2	yes	6.9	88.0	4300
9	medium	2	no	8.5	176.0	5000

FIG 5.6

LaRC IAX Extrusion Trial 2

Summary of Extrusion Sample Observations							
sample	wire diameter	tip num	tip dim	die num	die dim	K ¹	R ²
1	.0592	4-13	.150	4-36	.244	1.006	17.1
2	.0592	4-13	.150	4-36	.244	1.006	17.1
3	.0600	4-13	.150	4-36	.244	0.992	16.4
4	.0515	4-13	.150	4-36	.244	1.156	28.2
5	.0510	4-13	.150	4-36	.244	1.167	29.4
6	.0605	4-13	.150	4-36	.244	0.984	16.0
7	.0588/.0615	4-01	.125	4-26	.2045	1.018/0.974	12.4/10.7
8	.0590	4-01	.125	4-26	.2045	1.015	12.2
9	.0525	4-01	.125	4-26	.2045	1.141	18.49

¹ Ratio of strain in outer surface to strain in inner surface at extrusion die.

² Reduction ratio of flow cross-sectional area at extrusion die;

FIG 5.7

5. Testing and Evaluation.

Wire trials # 3 through 9 were subjected to testing. FIG 7.1 to 7.80 and FIG 8.1.

- A. Surface resistance requirement is 500 megohm inch after exposure to 97 % relative humidity for 96 hrs at 25° C, 500 volts D.C..

Initial resistance was greater than 1,000 megohm inch. 2500 VRMS at 60 Hz did not cause arching, dielectric failure, smoking. After 20 minutes exposure, the surface resistance was 600 megohm inch.

- B. Blocking involves testing 24 hrs at 200° C under 1 lb tension, wound on a coil. There was no sticking or adhesion, which is excellent.
- C. Flammability - a 24 inch specimen is held 60° horizontal and exposed to a Bunsen burner. The flame traveled only 1.25 inch - 3 inches allowed. There was no dripping or burning particles.
- D. Hot fluid immersion includes reverse bending, diameter measurements, post immersion in salt water with wetting agent and testing with 2500 Volts.
- E. Impulse dielectric requires 8.0 kVAC, and the wires passed.
- F. Insulation resistance required immersion in water with anionic wetting agent for 4 hours. The minimum resistance is 5,000 megohms/1000 ft., an outstanding 25,00 megohms/1000 ft was obtained.
- G. In low temperature cold bend the wire is subjected to -65°C, wound on a mandrel and held under tension, later subjected to winding. The LaRC™ IAX passes without cracking.
- H. Accelerated aging requires that the wire be wrapped around a 0.25 inch mandrel under tension. The wire is cycled 7 times through 230° C, 16 hrs each time, and held at room temperature for 8 hrs. The coils are straightened, then exposed to salt water and tested at 2500 volts for 1 minute.

Only sample number # 7 passed at 230° C, the others passed at 200° C. This indicates that insulation thickness influences the thermal resistance of the polymer. Sample # 7 was heavy wall.

- I. Finished weight was much better than required. The thin wall construction requires 5.36 lbs/1000 ft. maximum weight - 4.1 lbs was measured. Heavy wall construction has a maximum weight of 4.76 lbs/1000 ft. - 4.5 lbs was measured.
- J. Wire dimensions are critical. This wire was within specification.
- I. Shrinkage after 6 hrs at 200° C. These samples were subjected to 230° C and passed the requirement of 0.125 inch maximum shrinkage. The thin/medium wall shrunk only 0.012 inch and the thick wall only 0.012 inch.
- J. The coated wire was tested for stripability, necessary for connections. The wire insulation was readily stripped from the wire without peel back or splintering when the quenching bath was used.

SUMMARY

Test Data Sheet**Imitec/NASA Contract No. NAS1-20121**

Test	Test Specification	Sample Numbers						
		3	4	5	6	7	8	9
Surface Resistance	Mil-W-22759E	P	P	P	P	P	P	P
Blocking	Mil-W-22759E	P	P	P	P	P	P	P
Flammability	Mil-W-22759E	-	-	P	P	-	-	P
Fluid Immersion	Mil-W-22759E	Consist of visual and dielectric test						
a. Lubricating Oil	"	-	P	P	P	P	-	P
b. Hydraulic Fluid	"	-	P	P	P	P	-	P
c. Isopropyl Alcohol	"	-	F	F	F	F	-	F
d. Turbine Fuel	"	-	P	P	P	P	-	P
Impulse Dielectric	Mil-W-22759E	P	P	P	P	P	P	P
Insulation Resistance	Mil-W-22759E	P	P	P	P	P	P	P
Low Temp. Cold Bend	Mil-W-22759E	F	F	P	P	P	F	F
Accelerated Aging	Mil-W-22759E	See data sheet for dwell times						
a. 230°C	"	F	F	F	F	P	F	F
b. 200°C	"	P	-	P	-	P	-	P
Wire Weight	Mil-W-22759E	P	P	P	P	P	P	P
Wire Diameter	Mil-W-22759E	P	P	P	P	P	P	P
Shrinkage	Mil-W-22759E	P	P	P	P	P	P	P

Note: "P" indicates pass; "F" indicates fail; "-" indicates not done

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCOE WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 through 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: SURFACE RESISTANCE

Requirement: 500 megohm•inches (minimum), Initial and final readings

Test Spec: MIL-W-22759E, PARAGRAPH 4.6.3.18

Description of Test : (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Two electrodes of AWG 30 tin-coated copper wire were tightly wound around the circumference of a 6 inch specimen. A free end was left and attached to leads in the test chamber. The electrodes were spaced one inch apart near the center of the specimen. The test chamber was sealed and the specimen was conditioned for 96 hours at a temperature of 25°C and a relative humidity of 97%. At the end of 96 hours, the surface resistance was measured with a d.c. potential of 500 volts while the specimen was still in the test chamber. The surface resistance measurement was taken after 1 minute of electrification.

Following the initial resistance measurement, a 2500 VRMS, 60Hz-potential, was applied to the electrodes for 1 minute. There was no arcing, smoking, burning, flashover, or dielectric failure.

After a discharge interval of 20 minutes, the surface resistance was remeasured.

Initial Resistance Measurements: >1,000,000MΩ

Diameter of the specimen 0.0603"

Formula: Finished Wire Diameter X Resistance Measurements

Results: Initial Results: 60.000MΩ•inches
Final Results: 60.000MΩ•inches

Gary Rain
Tested By
Bruce Jell
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.1

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 THROUGH 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJEC
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: BLOCKING

Requirement: Adjacent turns or layers of the wire shall not stick to one another when tested at a temperature of $200^{\circ}\text{C} \pm 2^{\circ}\text{C}$.

Test Spec: MII-W-22759E, paragraph 4.6.3.5

Description of Test : (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information)

One end of the finished piece of wire was affixed to a mandrel three inches in diameter. The wire was wound helically on the spool for more than three turns, with each succeeding turn in contact with the other. The tension for winding was one lb. The winding was continued until there were three closely wound layers. The free end of the wire was affixed to the spool to prevent unwinding and loosening. The mandrel and wire were placed in an air circulating oven for 24 hours at $200^{\circ}\text{C} \pm 2^{\circ}$. At the end of the 24 hour period, the wire and mandrel were removed from the oven and allowed to cool to room temperature. After cooling, the wire was unwound manually and examined for evidence of sticking or adhesion of adjacent turns or layers.

Results: There was no sticking or adhesion of adjacent turns or layers.

Gary Rainey
Tested By
Gary Janh
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.2

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 5, 6, AND 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: FLAMMABILITY

Requirement: 3.0 seconds, maximum, after-flame burn

3.0 inches, maximum, flame travel

No flaming of tissue paper

Post-flame Dielectric Test - Not Required

Test Spec: MII-W-22759E, PARAGRAPH 4.6.3.14

Description of Test : (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Apparatus: Test Chamber and Bunsen Burner meet the descriptions and requirements of Section 2.A

A 24 inch specimen of the finished wire was placed horizontally in the test chamber and held taut at an angle of 60° horizontal, in a plane parallel to and approximately 6 inches from the rear wall of the chamber. A sheet of facial tissue was suspended horizontally and held taut 9.5 inches below the point of application of the flame. A three inch flame was applied 8 inches from the lower end of the specimen. The flame was applied for 30 seconds and withdrawn immediately at the end of that time.

Results: After-flame Burn: 0 seconds
Flame Travel: 1.25 inches
Flaming of Tissue: None

Mary Raine
Tested By
Barry Smith
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.3

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER:	IMITEC	PROJECT:	NASA PROJECT
WORK ORDER:	EXPERIMENTAL	REQUESTED BY:	JACK KEATING
SAMPLE NO.:	4, 5, 6, 7, 9	DUE DATE:	6/24/94
DESCRIPTION:	WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LARC-1AX		

Test Name: FLUID IMMERSION

Requirement: Diameter increase: 5% max. There shall be no cracking of the insulation when subjected to the Bend Test of para. 4.6.3.15.2 and no dielectric breakdown when tested per the Wet Dielectric Test of para. 4.6.3.15.3.

Test Spec: MII-W-22759E, PARAGRAPH 4.6.3.16

Description of Test (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Specimen Length: 48"

Prior to immersion into the fluids, the initial diameter of the finished wire was measured and recorded. Specimens of finished wire were then immersed to within 6 inches of their ends in each of the fluids, and at the temperatures and for the length of time listed below. Upon removal from the liquids, the specimens remained in free air at room temperature for one hour. The diameter of the finished wire was again measured and recorded. One inch of insulation was then removed from each end of each of the specimens. One end of each specimen was secured to a .75 inch mandrel and subjected to two reverse bends under a load weight of 1.0 lbs. Each specimen was inspected for cracking. The specimen was then immersed for 5 hours in a 5% by weight solution of sodium chloride, and containing 5% anionic wetting agent. Each end of the wire extended 2.50 inches above the surface of the solution. At the end of 5 hours, 2500 volts rms, was applied between the conductor and the electrode (in contact with the solution).

FIG 7.4

FLUID IMMERSION, SAMPLE NO.4

FLUID	FLUID TEMP	DURATION	OD INITIAL	OD FINAL	CHANGE
LUBRICATING OIL	120°F	20 HOURS	.0584"	.0584"	0.0%
HYDRAULIC FLUID	121°F	20 HOURS	.0584"	.0584"	0.0%
ISOPROPYL ALCOHOL	70°F	20 HOURS	.0584"	.0582"	+0.30%
TURBINE FUEL	70°F	20 HOURS	.0584"	.0583"	+0.10%

Results: There was no evidence of cracking, no dielectric breakdown, and no pitting of conductor when subjected to all fluids other than isopropyl alcohol. There is incompatibility of this material in an environment of isopropyl alcohol evidenced in cracking throughout specimen.

<p><i>Gary Rain</i> ----- Tested By</p> <p><i>Gary Joub</i> ----- Approved By</p>	<p><i>6/24/94</i> ----- Date</p> <p><i>6/24/94</i> ----- Date</p>
---	---

FIG 7.41

FLUID IMMERSION, SAMPLE NO. 5

FLUID	FLUID TEMP	DURATION	OD INITIAL	OD FINAL	CHANGE
LUBRICATING OIL	120°F	20 HOURS	.0515"	.0519"	+0.70%
HYDRAULIC FLUID	121°F	20 HOURS	.0515"	.0517"	+0.30%
ISOPROPYL ALCOHOL	70°F	20 HOURS	.0515"	.0505"	-1.90%
TURBINE FUEL	70°F	20 HOURS	.0515"	.0515"	0.0%

Results: There was no evidence of cracking, no dielectric breakdown, and no pitting of conductor when subjected to all fluids other than isopropyl alcohol. There is incompatibility of this material in an environment of isopropyl alcohol evidenced in cracking throughout specimen.

Gary Rainis
 Tested By
Barry J. Lark
 Approved By

6/24/94
 Date
 6/28/94
 Date

FIG 7.42

FLUID IMMERSION, SAMPLE NO. 6

FLUID	FLUID TEMP	DURATION	OD INITIAL	OD FINAL	CHANGE
LUBRICATING OIL	120°F	20 HOURS	.0595"	.0599"	+0.60%
HYDRAULIC FLUID	121°F	20 HOURS	.0595"	.0599"	+0.60%
ISOPROPYL ALCOHOL	70°F	20 HOURS	.0595"	.0593"	-0.30%
TURBINE FUEL	70°F	20 HOURS	.0595"	.0597"	+0.30%

Results: There was no evidence of cracking, no dielectric breakdown, and no pitting of conductor when subjected to all fluids other than isopropyl alcohol. There is incompatibility of this material in an environment of isopropyl alcohol evidenced in cracking throughout specimen.

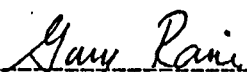
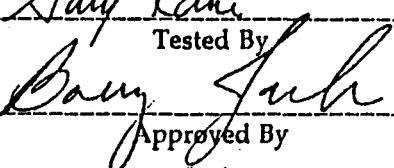
<p><i>Amy Rain</i> ----- Tested By</p> <p><i>Dany Larr</i> ----- Approved By</p>	<p><i>6/24/94</i> ----- Date</p> <p><i>6/28/94</i> ----- Date</p>
--	---

FIG 7.43

FLUID IMMERSION, SAMPLE NO. 7

FLUID	FLUID TEMP	DURATION	OD INITIAL	OD FINAL	CHANGE
LUBRICATING OIL	120°F	20 HOURS	.0603"	.0611"	+1.30%
HYDRAULIC FLUID	121°F	20 HOURS	.0603"	.0610"	+1.10%
ISOPROPYL ALCOHOL	70°F	20 HOURS	.0603"	.0598"	+0.80%
TURBINE FUEL	70°F	20 HOURS	.0603"	.0604"	+0.10%

Results: There was no evidence of cracking, no dielectric breakdown, and no pitting of conductor when subjected to all fluids other than isopropyl alcohol. There is incompatibility of this material in an environment of isopropyl alcohol evidenced in cracking throughout specimen.


 Tested By

 Approved By


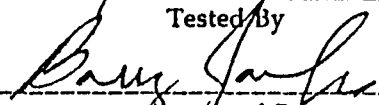
6/24/94
 Date
 6/25/94
 Date

FIG 7.44

FLUID IMMERSION, SAMPLE NO. 9

FLUID	FLUID TEMP	DURATION	OD INITIAL	OD FINAL	CHANGE
LUBRICATING OIL	120°F	20 HOURS	.0519"	.0519"	0.0%
HYDRAULIC FLUID	121°F	20 HOURS	.0519"	.0519"	0.0%
ISOPROPYL ALCOHOL	70°F	20 HOURS	.0519"	.0512"	+1.30%
TURBINE FUEL	70°F	20 HOURS	.0519"	.0520"	+0.10%

Results: There was no evidence of cracking, no dielectric breakdown, and no pitting of conductor when subjected to all fluids other than isopropyl alcohol. There is incompatibility of this material in an environment of isopropyl alcohol evidenced in cracking throughout specimen.


 Tested By

 Approved By

6/24/94
 Date
 6/24/94
 Date

FIG 7.45

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER:	IMITEC	PROJECT:	NASA PROJECT
WORK ORDER:	EXPERIMENTAL	REQUESTED BY:	JACK KEATING
SAMPLE NO.:	3 THROUGH 9	DUE DATE:	6/24/94
DESCRIPTION:	WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX		

Test Name: IMPULSE DIELECTRIC TEST

Requirement: 100% of the wire shall be tested at 8.0 kVAC (peak)

Test Spec: MII-W-22759E, PARAGRAPH 4.6.3.1

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Test 100% of the finished wire

Test Equipment: Clinton Impulse Spark Tester
Model IT-25-B, Serial Number 481

Test Temperature: Ambient

Test Voltage: Recommended per SAE AS 4373, 6.5 kVA (Peak) minimum.

Test voltage for finished wire was 8.0 kVA (peak).

Number of failures: 8

Note: Dielectric failures are flagged and removed during the final inspection process, so that there are no defects in final product (as shipped).

Gary Rani
Tested By
Bary Jank
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.5

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 through 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: INSULATION RESISTANCE

Requirement: 5,000 Megohms/1,000 ft. minimum

Test Spec: MIL-W-22759E, PARAGRAPH 4.6.3.2

Description of Test (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information)

Number of Samples: 1

Sample Length: 26 ft. (Immersed Length: 25 ft.)

Test Solution: Water bath containing 1.0% anionic wetting agent (Aerosol OT)

Test Equipment: Associated Research Vibrotest Megohmmeter, Model 2850

Test Temperature:Bath Temp: 21° C

Resistance Measurement: >1,000,000MΩ

Test Duration: Immersion: 4 hours

Electrification: 1 minute

Test Potential: 500 volts

Formula:
$$\frac{\text{Reading in megohms} \times \text{Immersed length}}{1,000}$$

Results: 25,000 Megohms/1000 ft.

Comments: All readings were consistently beyond measurement scale of equipment.

Gary Rain
Tested By
Gary Jacobs
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.6

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: LOW TEMPERATURE COLD BEND

Requirement: The wire shall withstand a temperature of $-65^{\circ}\text{C} \pm 2^{\circ}\text{C}$. There shall be no cracking of the insulation upon bending and no dielectric breakdown when tested in accordance with the Wet Dielectric Test of para. 4.6.3.15.3

Test Specs: MIL-W-22759E, PARAGRAPHS 4.6.3.12 and 4.6.3.15.3

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from each end of a 24 inch sample of the finished wire. One end of the specimen was affixed to a mandrel, and placed under tension using the test load below. The sample was placed in the cold box at the specified temperature of $-65^{\circ}\text{C} \pm 2^{\circ}$ for a minimum of 4 hours. After completion of the low temperature exposure the specimen was wrapped around a mandrel for its full length at a constant rate of 2 RPM ± 1 . After winding, the specimen was relieved of tension, removed from the mandrel, and examined for cracks.

Test Load	Mandrel Diameter	Temperature	Duration
1.0 Lbs.	1.0"	$-65^{\circ}\text{C} \pm 2^{\circ}$	four hours

Results: There was evidence of cracking.

Gary Rainey
Tested By
Barry Jacobs
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.7

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 4, 8, 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: LOW TEMPERATURE COLD BEND

Requirement: The wire shall withstand a temperature of $-65^{\circ}\text{C} \pm 2^{\circ}\text{C}$. There shall be no cracking of the insulation upon bending and no dielectric breakdown when tested in accordance with the Wet Dielectric Test of para. 4.6.3.15.3

Test Specs: MIL-W-22759E, PARAGRAPHS 4.6.3.12 and 4.6.3.15.3

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from each end of a 24 inch sample of the finished wire. One end of the specimen was affixed to a mandrel, and placed under tension using the test load below. The sample was placed in the cold box at the specified temperature of $-65^{\circ}\text{C} \pm 2^{\circ}$ for a minimum of 4 hours. After completion of the low temperature exposure the specimen was wrapped around a mandrel for its full length at a constant rate of $2\text{ RPM} \pm 1$. After winding, the specimen was relieved of tension, removed from the mandrel, and examined for cracks.

Test Load	Mandrel Diameter	Temperature	Duration
1.0 Lbs.	1.0"	$-65^{\circ}\text{C} \pm 2^{\circ}$	four hours

Results: There was no evidence of cracking

After completing visual examination of the finished wire specimen, the wire was immersed in a 5%, by weight, saline solution at a temperature of 21°C for 5 hours. The ends of the wire extended 6 inches above the level of liquid. At the end of the immersion period, a potential of 2500 volts was applied between the conductor and an electrode in the solution.

Duration (Electrification): 5 minutes

Results: Failed wet dielectric.

Gary Paine
Tested By
Gary Paine
Approved By

6/24/94
Date
6/28/94
Date

FIG 7.71

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 5, 6, 7
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: LOW TEMPERATURE COLD BEND

Requirement: The wire shall withstand a temperature of $-65^{\circ}\text{C} \pm 2^{\circ}\text{C}$. There shall be no cracking of the insulation upon bending and no dielectric breakdown when tested in accordance with the Wet Dielectric Test of para. 4.6.3.15.3

Test Specs: MIL-W-22759E, PARAGRAPHS 4.6.3.12 and 4.6.3.15.3

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from each end of a 24 inch sample of the finished wire. One end of the specimen was affixed to a mandrel, and placed under tension using the test load below. The sample was placed in the cold box at the specified temperature of $-65^{\circ}\text{C} \pm 2^{\circ}$ for a minimum of 4 hours. After completion of the low temperature exposure the specimen was wrapped around a mandrel for its full length at a constant rate of 2 RPM ± 1 . After winding, the specimen was relieved of tension, removed from the mandrel, and examined for cracks.

Test Load	Mandrel Diameter	Temperature	Duration
1.0 Lbs.	1.0"	$-65^{\circ}\text{C} \pm 2^{\circ}$	four hours

Results: There was no evidence of cracking

After completing visual examination of the finished wire specimen, the wire was immersed in a 5%, by weight, saline solution at a temperature of 21°C for 5 hours. The ends of the wire extended 6 inches above the level of liquid. At the end of the immersion period, a potential of 2500 volts was applied between the conductor and an electrode in the solution.

Duration (Electrification): 5 minutes

Results: There was no evidence of dielectric breakdown.

Gary Rain
Tested By
Darryl Sachs
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.72

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 4,5,6,8
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: ACCELERATED AGING

Requirement: There shall be no cracking of the insulation. The specimen shall then pass the Wet Dielectric Test of MIL-W-22759E, PARA. 4.6.3.15.3

Test Spec: BSS-7324 AND MIL-W-22759E

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from both ends of a 24 inch sample of the finished wire. The central portion of the specimen was bent over a .250 inch mandrel wrapped with PTFE tape, and placed under tension using a test load of .750 pounds on each wire end. The sample was placed in an air circulating oven at a temperature of $230^{\circ}\pm 10^{\circ}\text{C}$. After completion of the oven exposure for 16 hours, the specimen was allowed to cool to room temperature for a period of 8 hours. This cycle was repeated 6 more times for a total of 7 cycles. When conditioning was completed, the specimen was relieved of tension, removed from the mandrel, straightened and examined for cracks.

Number of Specimens: Two/Sample

Mandrel Diameter: .250"

Duration (Oven exposure): 168 HRS.

Results: There was no evidence of insulation cracking

After completing the visual examination of the wire specimen, the wire was immersed in a 5% by weight saline solution, at a temperature of 21°C for 4 hours. The ends of the immersed wire extended 6 inches above test solution. At the end of the immersion period, a potential of 2500 VRMS was applied between the conductor and an electrode in the solution.

Duration (Electrification): 1 minute

Results: There was dielectric breakdown on all specimens.

Gary Cain
Tested By
Barry Spahr
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.8

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 7
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: ACCELERATED AGING

Requirement: There shall be no cracking of the insulation. The specimen shall then pass the Wet Dielectric Test of MIL-W-22759E, PARA. 4.6.3.15.3

Test Spec: BSS-7324 AND MIL-W-22759E

Description of Test (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from both ends of a 24 inch sample of the finished wire. The central portion of the specimen was bent over a .250 inch mandrel wrapped with PTFE tape, and placed under tension using a test load of .750 pounds on each wire end. The sample was placed in an air circulating oven at a temperature of $230^{\circ}\pm 10^{\circ}\text{C}$. After completion of the oven exposure for 16 hours, the specimen was allowed to cool to room temperature for a period of 8 hours. This cycle was repeated 6 more times for a total of 7 cycles. When conditioning was completed, the specimen was relieved of tension, removed from the mandrel, straightened and examined for cracks.

Number of Specimens: Two/Sample

Mandrel Diameter: .250"

Duration (Oven exposure): 168 HRS.

Results: There was no evidence of insulation cracking or dielectric breakdown.

After completing the visual examination of the wire specimen, the wire was immersed in a 5% by weight saline solution, at a temperature of 21°C for 4 hours. The ends of the immersed wire extended 6 inches above test solution. At the end of the immersion period, a potential of 2500 VRMS was applied between the conductor and an electrode in the solution.

Duration (Electrification): 1 minute

Results: There was no evidence of insulation cracking or dielectric breakdown.

Gary Rainey
Tested By
Bruce Smith
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.81

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3, 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: ACCELERATED AGING

Requirement: There shall be no cracking of the insulation. The specimen shall then pass the Wet Dielectric Test of MIL-W-22759E, PARA. 4.6.3.15.3

Test Spec: BSS-7324 AND MIL-W-22759E

Description of Test: (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from both ends of a 24 inch sample of the finished wire. The central portion of the specimen was bent over a .250 inch mandrel wrapped with PTFE tape, and placed under tension using a test load of .750 pounds on each wire end. The sample was placed in an air circulating oven at a temperature of $230^{\circ}\pm 10^{\circ}\text{C}$. After completion of the oven exposure for 16 hours, the specimen was allowed to cool to room temperature for a period of 8 hours. This cycle was repeated 6 more times for a total of 7 cycles. When conditioning was completed, the specimen was relieved of tension, removed from the mandrel, straightened and examined for cracks.

Number of Specimens: Two/Sample

Mandrel Diameter: .250"

Duration (Oven exposure): 168 HRS.

Results: There was evidence of insulation cracking on specimen 1 of both samples 3 and 9

After completing the visual examination of the wire specimen, the wire was immersed in a 5% by weight saline solution, at a temperature of 21°C for 4 hours. The ends of the immersed wire extended 6 inches above test solution. At the end of the immersion period, a potential of 2500 VRMS was applied between the conductor and an electrode in the solution.

Duration (Electrification): 1 minute

Results: There was dielectric breakdown on specimens 1 of both samples 3 and 9.

Gary Rain

Tested By
Darryl Gault

Approved By

6/24/94

Date
6/24/94

Date

FIG 7.82

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3, 5, 7, 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: ACCELERATED AGING

Requirement: There shall be no cracking of the insulation. The specimen shall then pass the Wet Dielectric Test of MIL-W-22759E, PARA. 4.6.3.15.3

Test Spec: BSS-7324 AND MIL-W-22759E

Description of Test (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

One inch of insulation was removed from both ends of a 24 inch sample of the finished wire. The central portion of the specimen was bent over a .250 inch mandrel wrapped with PTFE tape, and placed under tension using a test load of .750 pounds on each wire end. The sample was placed in an air circulating oven at a temperature of $200^{\circ}\pm 10^{\circ}\text{C}$. After completion of the oven exposure for 24 hours, the specimen was allowed to cool to room temperature for a period of 8 hours. When conditioning was completed, the specimen was relieved of tension, removed from the mandrel, straightened and examined for cracks.

Number of Specimens: Two/Sample

Mandrel Diameter: .250"

Duration (Oven exposure): 24 HRS.

Results: There was no evidence of insulation cracking or dielectric breakdown.

After completing the visual examination of the wire specimen, the wire was immersed in a 5% by weight saline solution, at a temperature of 21°C for 4 hours. The ends of the immersed wire extended 6 inches above test solution. At the end of the immersion period, a potential of 2500 VRMS was applied between the conductor and an electrode in the solution.

Duration (Electrification): 1 minute

Results: There was no evidence of insulation cracking or dielectric breakdown.

Gary Rainey
Tested By
Gary Rainey
Approved By

6/24/94
Date
6/24/94
Date

FIG 7.83

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 THROUGH 9
DESCRIPTION: WIRE,ELECTRICAL,EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: FINISHED WIRE WEIGHT

Requirement: Finished wire weight shall not exceed:
5.36 lbs/1,000 ft. (22759/16); 4.76 lbs/1,000 ft. (22759/18)

Test Spec: MII-W-22759E and MIL-STD-2223, Method 6001

Description of Test: (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Number of Samples: FOUR/MEDIUM WALL; FOUR/HEAVY WALL.

Sample Length: 10 ft.

Test Equipment: Mettler Digital Scale, Model PE 3600

Test Temperature: Ambient 72°

The actual weight of the finished wire specimen:

LIGHT WALL 4.1 POUNDS/1,000 ft.

MEDIUM WALL 4.5 POUNDS/1,000 ft.

Comments: SUBSTANTIAL WEIGHT SAVINGS REALIZED UTILIZING THIS INSULATION SYSTEM OVER ETFE

Gary Rain
Tested By
Darryl Locks
Approved By

6/24/94
Date
6/28/94
Date

FIG 7.9

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 THOUGH 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDE POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: WIRE DIMENSIONS

Requirement: Finished wire diameter shall not exceed:
0.049"-0.253" (22759/18); 0.058"-0.062" (22759/16)

Test Spec: M22759E, SLASH SHEETS 16 AND 18

Description of Test (include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information):

Number of Samples: FOUR/MEDIUM WALL; FOUR/HEAVY WALL.

Number of Readings: 10

Test Equipment: Mitutoyo Digital Micrometer, Model 293-311

Primary Wire Results:

LIGHT WALL	MIN: 0.0510"	MAX: 0.0523"	AVG: 0.0519"
MEDIUM WALL	MIN: 0.0595"	MAX: 0.0614"	AVG: 0.0603"

Gary Rain
Tested By
Darryl Johns
Approved By

6/24/94
Date
6/24/94
Date

FIG 8.0

Test Data Sheet

Imitec/NASA Contract No. NAS1-20121

BARCEL WIRE AND CABLE CORP

IRVINE, CA

CUSTOMER: IMITEC
WORK ORDER: EXPERIMENTAL
SAMPLE NO.: 3 THROUGH 9
DESCRIPTION: WIRE, ELECTRICAL, EXTRUDED POLYIMIDE INSULATED, LaRC-1AX

PROJECT: NASA PROJECT
REQUESTED BY: JACK KEATING
DUE DATE: 6/24/94

Test Name: SHRINKAGE At 230°C

Requirement: 0.125 inch maximum @ 200°C ± 2°C

Test Spec: MIL-W-22759E SLASH SHEETS 16 AND 18

Description of Test : (Include # of samples, mandrel diameters, test loads, test voltages, test temperatures, duration, quantitative results-when applicable-and other appropriate information)

One inch of insulation was stripped from each end of a fourteen inch specimen of finished wire. The length of exposed conductor at each end was measured to the nearest 0.01 inch. The sample was then placed in an air circulating oven for 6 hours at a temperature of 230°C. At the end of this period, the specimen was removed from the oven and allowed to cool to room temperature. Shrinkage of the insulation was measured as the greatest additional distance which any layer of the insulation receded from either end of the conductor. The shrinkage measurements were taken from both ends of two specimens from each sample and recorded.

Number of samples: FOUR/MEDIUM WALL; FOUR/HEAVY WALL.

Results: HIGHEST READING LIGHT WALL: 0.015"
HIGHEST READING MEDIUM WALL: 0.012"

Note: Samples were subjected to a temperature of 230°C (exceeding the required 200°C value) to reflect the notable thermal properties of this material.

Gary Rainey
Tested By
Danny Jacobs
Approved By

6/24/94
Date
6/24/94
Date

FIG 8.1

Summary:

Extrusion Equipment requirements:

1. A single screw extruder equipped with the following:
 - a. High temperature extruder barrel heaters required, either cast bronze or ceramic heaters should be used. Mica band heaters and aluminum cast heaters are not suitable.
 - b. The barrel must be equipped with an over-pressure relief on the clamp ring, such as a clamp shear pin. For safety reasons, bolt-on cross heads are not recommended. Standard over-pressure plugs may not work in the event of a mishap because the plastic is likely to solidify in the pressure plug stem.
 - c. The crosshead and adapter flange and barrel clamp require substantial thermal blanket insulation to reduce heat loss.
 - d. LaRC™ IAX in the molten state does not attack iron. Expensive, exotic nickel alloys such as Hastaloy C and Duranickel are not required. Extruder screw, barrel and tooling can be fabricated using conventional nitrided alloy steel.
 - e. A conventional gradual taper transition Nylon type screw is recommended with a compression ratio of 2.8:1 to 3.1:1, and having 6 flites in the metering section.
 - f. Extruder barrel with an L/D ratio of 24:1 or greater is ideal.
 - g. The high melt temperatures makes moisture pickup a greater problem than with lower temperature plastics. A de-humidifying hopper-dryer is needed with a desiccant cartridge bed capable of operating at 120° F, with air recirculation through the hopper.
 - h. The extruder should be equipped with a low speed DC (or digital) tachometer feedback system for precise control of the extruder at very low RPM and high torque.
 - i. The LaRC™ IAX is a tough polymer, motor overload conditions are easily reached and need to be monitored. A pressure transducer with a range greater than 7,500 psi is needed in the barrel wall before the breaker plate.

2. Extrusion Tooling:

- a. Conventional tooling geometry for the extrusion of Nylon and PVC is a good starting point. Use the tubing technique with low draw down ratio for extruding onto wire.
- b. Use a slightly under-balanced draw.
- c. Apply vacuum at the crosshead to compensate for the draw.
- d. Use a breaker plate with no finer than 80 mesh screens, well supported to prevent puncture.
- e. The crosshead adapter volume should be constructed to have the smallest polymer volume possible - avoiding temperature gradients in the melt.
- f. Do not use silicone grease in contact with the tooling.

3. Extrusion conditions:

- a. Extrude into hot water, above 150° F. Cold quenching results in poor elongation of the polymer. No quenching results in a coating that shrinks tightly to the wire and is difficult to strip.
- b. Quench distance from the crosshead is related to line speed. If the distance is too short, stress fractures are induced in the extruded coating. This relationship must be determined while processing the polymer.

4. Processing Observations:

1. Preconditioning:

- a. The pelletized LaRC™ IAX must be dried before extruding, and polymer feed kept dry. Absorbed moisture causes the polymer to coagulate at the die, resulting in rough coatings, in the same manner as with polyethylene and nylon resins. Moisture causes microscopic bubbles, almost undetectable in the product. These voids decrease elongation, lead to fractures and flexibility failures.
- b. When the shear is increased in the extruder, ultimate polymer elongation increases and the horsepower requirements in the extruder during extrusion decrease.

2. Resin Temperature Stability:

- a. The LaRC IAX does not form gel particles when the melt is exposed to iron. Long dwell times at elevated temperatures

did not advance the melt viscosity. The polymer is very thermally stable and scrap can be reclaimed for reuse.

Comparison of Wire Properties:

Commercial and military wire styles in current usage for new design are limited. Wire and cables are high temperature, high performance and light weight designs. Integration of wire and cable into broad usage has resulted in a sophisticated set of requirements that encompass four areas, environmental resistance, physical properties, electrical properties and installation.

The tests selected in this study represent some of the most significant properties enumerated in military and commercial specifications. The selected tests are held in common by all three existing wire types, which are;

1. MIL-W-81381/7 through/23. These wires are composed of one or more insulation layers of helically applied FEP coated Kapton (polyimide tape), with an overcoat of pigmented Imitac modified polyimide topcoat.

2. MIL-W-22759-34 through 43 constructions. These wires are composed of extruded ethylenetetrafluoroethylene fluoropolymer (ETFE) crosslinked by electron beam irradiation, Tefzel type.

3. Composite constructions. These wires are composed of two or more layers of materials.

The wire test data from the extruded LaRC™ IAX at Barcel Wire & Cable shows excellent passing performance:

- a. Excellent abrasion resistance. This results in a durable, crush and wear resistant wire. Wire handling and pulling of wire harnesses would be facilitated.
- b. Excellent dielectric strength, a good insulator in thin thickness.
- c. Low specific gravity. Low weight wire constructions.
- d. Non-flammability. Without flame retardants the wire does not burn.
- e. Non-blocking. At elevated temperatures encountered in use and cable fabrication, the insulation will not flow or stick together.

- f. Resistant to solvents, not affected by fluids encountered in aviation. Excellent hydrolysis resistance. Current polyimide constructions in aircraft are susceptible to hydrolysis and are not permitted in SWAMP areas - wheel wells, wings, bellies of aircraft where sillage, waste, air impingement or petroleum products may exist.
- g. Unaffected by low temperatures, does not become brittle at low temperatures - cold bend test.
- h. Melt processable and can be formed into thin insulation on conventionally available equipment.
- i. Good elevated temperature properties, 200 and 230° C.

July 25, 1994.

Mr. Jack Keating
VP Sales and Marketing
IMITEC, Inc.
P.O. Box 1412
1990 Maxon Road
Schenectady, NY 12301
Fax: (518) 374-4299

2851

Alion

Re: New Technology (NASA 20121)

Avenue

10000

Dear Jack,

California

In view of the promising results exhibited with the extruded NASA polymer, LaRC IAX, we have made the following conclusions:

92714.5885

1. **Processability** - The material is relatively easy to process. Diameters are controllable and both thin wall and medium wall constructions are produceable. There was no outgassing observed during the runs.

17X

910.595.1957

2. **Preliminary Test Results** - We are encouraged with the excellent test results in the areas of mechanical, environmental and electrical. Compared to existing constructions, and constructions currently in development, this polymer appears to meet all critical requirements. Compared to other materials we have evaluated in the past the NASA polymer has surpassed our expectations at this stage of the development cycle.

1AX

714.063.9766

3. **Cost To Produce** - Based on our running speeds, scrap rates, etc., we project our cost to produce this product to be considerably less than costs to produce comparable products currently in use. As you know most of the OEM constructions are tape wrapped (Boeing's BMS 13-60 and Douglas' BXS 7007) which is a costly process.

III

714.063.0360

4. **Customer Reaction** - McDonnell Douglas Engineering is very interested in this product. Douglas is currently in a Wire Evaluation Program and the NASA polymer could prove it's worth at Douglas if we move quickly. Douglas, of course, needs more data and has strongly urged us to provide them with samples, etc. as soon as possible.

Jack, all the staff at Barcel remains excited and encouraged with the progress to date. We hope we can continue this project through its introduction and acceptance into the marketplace. LARC IAX is as promising as any new product we have evaluated. We look forward to working with you further on this program and offer you our continued support.

Thank you for your confidence in Barcel.

Sincerely,

A handwritten signature in cursive script, appearing to read "B. E. Inman".

B. E. Inman
President

BARCEL WIRE AND CABLE

Conclusion:

Extruded LaRC™ IAX polyimide polymer exhibits excellent properties on stranded aircraft wire. The light weight and other properties merit its evaluation in satellites, missiles and aircraft applications.

The LaRC™ IAX as an aircraft cable insulation will result in lower weight aircraft. The product results in a polyimide aircraft insulation without seams, outstanding moisture resistance, continuous lengths, and is abrasion resistant. The product does not burn and has good cold and high temperature properties. The product does not shrink during use and can be stripped from the cables, facilitating connections.

Polyimide has the best electrical strength vs. thickness, enabling thin coatings and low weight. The electrical characteristics of the IAX are excellent.

The IAX melts readily in an extruder and has low viscosity, facilitating the process and manufacture of thin wall coatings. Extruders equipped to process Tefzel™ will readily extrude the IAX. The product does not corrode the extruder, develop gel particles or advance in viscosity.

The LaRC™ IAX is light colored and can be readily tinted and laser marked.

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6. AUTHOR(S) Jack Keating				
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13. ABSTRACT (Maximum 200 words) TM NASA Langley has invented LaRC TM IA and IAX which are thermoplastic polyimides with good melting, thermal and chemical resistance properties. It was the objective of this contract to prepare and extrude LaRC TM polyimide onto aircraft wire and evaluate the polymers performance in this critical application. Based on rheology and chemical resistance studies at Imitec, LaRC TM IAX was selected. Pelletized IAX polyimide was extruded onto stranded aircraft wire at Barcel Wire and Cable Corporation. The IAX melts readily in an extruder, facilitating the manufacture of thin wall coatings. The polyimide does not corrode the extruder, develop gel particles nor advance in viscosity. The insulated wire was tested according to MIL-W-22759E test specifications. The resulting wire coated with LaRC TM IAX displayed exceptional properties: surface resistance, non blocking, non burning, hot fluid resistance, impulse dielectric, insulation resistance, low temperature flexibility, thermal aging, wire weight, dimensions, negligible high temperature shrinkage and stripability. The light weight and other properties merit its application in satellites, missiles and aircraft applications. The extruded IAX results in a polyimide aircraft insulation without seams, outstanding moisture resistance, continuous lengths and abrasion resistance.				
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